RECENT GUN CHARACTERISATION RESULTS AT PITZ

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CONTENT

▶ PITZ1.7 setup
  – Gun cavity and dark current.
  – Cathode laser system
  – Diagnostics overview
  – Transverse projected emittance measurements and rf conditions
  – New emittance measurement procedure

▶ Results
  – Projected emittance @ nominal charge of 1nC and emittance VS charge cut
  – Short and long term reproducibility
  – Lowest emittance @ 1nC
  – Projected emittance for different charge and emittance VS charge cut
  – High average current operation
Main properties of PITZ gun:

- 1.3 GHz cavity, coaxial RF coupler
- Capable of high average power → long electron bunch trains
- Very low normalized transverse emittance
Dry-ice sublimation-impulse cleaning → **significant dark current reduction**

Vertical cleaning setup with 110° rotating nozzle.

**GUN4.2 DARK CURRENT**

allows high brightness, high average current operation: 1 mA in 700 μs, 7 μA long term average
CATHODE LASER BEAM

Usually we use a flat-top pulse with FWHM ~ 23ps

pulse train repetition rate 10Hz

1 nC, 20ps

1 us and up to 800 pulses
GUN 4.2

Booster cavity

Dispersive sections

Streak camera read out ports

Emittance measurement systems

Slice emittance diagnostics

Quads, steerers, ICTs, FCs, BPMs
YAG/OTR, wire scanners
A single slit is scanned across the beam profile. The beam part that passes through is emittance dominated. The divergence is measured at a screen. To get the trace space distribution the divergence profiles are combined versus slit position.
Emittance value is evaluated as:

\[ \varepsilon_x = \beta \gamma \sqrt{X_{rms}^2 \cdot X_{rms}''^2 - \text{corr}(X, X')^2} \cdot \frac{X_{EMSY}^{rms}}{X_{rms}} \]

- \(X_{rms}^2, X_{rms}''^2, \text{corr}(X, X')\): second statistical moments of trace space distribution
- \(\beta \gamma \approx \frac{p_z}{m_0 c}\): normalized longitudinal momentum

\((\frac{X_{EMSY}^{rms}}{X_{rms}}) > 1\): scaling

- \(X_{EMSY}^{rms}\): beam size measured with a screen at EMSY
- \(X_{rms}\): beam size estimated from slit scan

To compensate possible sensitivity limitations for estimating the 100% RMS emittance (charge density of beamlets after drift is much lower than charge density of full beam)
RF INSTABILITY

Phase slope within an RF pulse ~5deg/40us

Fluctuations:
- 10..15deg (p-p)
- 2..4 deg (rms)

“10”-MW klystron is working close to the saturation, no LLRF regulation!

Now PITZ has installed unique 10MW directional in-vacuum coupler beginning 2010 (RF regulation like in FLASH possible).

BUT all measurements shown in the talk still include strong phase jitter.
RF phase variation leads to beam size and position change

Period of phase drift is short compared to the measurement time

Measured beam phase space volume is smeared out by the instability!
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MEASUREMENT PROCEDURE MODIFICATION

> Old emittance measurement procedure:

1. Move the slit to a measurement position.
2. Take 10 frames of the beamlet at observation screen and save it, go to 1
   - Fast scan for one plane: 200 s

> New emittance measurement procedure:

1. Move slit with a constant speed across the beam
2. Capture a sequence of frames of the beam on observation screen with 10 Hz
3. Save the sequence when the slit has reached the final position
4. for statistics the process can be repeated
   - Fast scan for one plane: 20 s

> The new procedure is less sensitive to the rf phase fluctuations

> Now we have an online raw data quality display:
Transverse projected emittance measurements
NOMINAL CHARGE OF 1nC

2D emittance for BSA=1.5mm, 1nC, gun: 6deg off-crest, booster: on-crest

\[ \varepsilon_x = 0.76 \text{ mm mrad} \]
\[ \varepsilon_y = 1.26 \text{ mm mrad} \]

(100% RMS emittance data !)
Now with charge cut:

Charge is cut corresponding to an equal density contour of a trace space distribution.
SHORT TERM REPRODUCIBILITY

\[ \varepsilon_x = 0.721 \pm 0.013 \text{ mm mrad} \]

- Q=1nC
- Imain=387mA
- Gun: +6deg off-crest
- Booster: on-crest
- Laser temp.: 2.1/23.1/2.4 ps
- Laser BSA=1.5mm

X-X’ phase space

PRELIMINARY RESULTS

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**SHORT TERM REPRODUCIBILITY**

\[ \varepsilon_y = (1.089 \pm 0.020) \text{ mm mrad} \]

- \(Q=1\text{nC}\)
- \(Imain=387\text{A}\)
- Gun: +6deg off-crest
- Booster: on-crest
- Laser temp.: 2.1/23.1/2.4 ps
- Laser BSA=1.5mm

**PRELIMINARY RESULTS**

Y-Y' phase space

- Beam @ EMSY1

**Graphs:**

- 22.08.2009; 12:47
- 22.08.2009; 12:50
- 22.08.2009; 12:53
- 22.08.2009; 12:56

**Detailed Parameters:**

- \(I_{max}=386.6 \text{[A]}, 13 \text{ pulses}\)
- \(I_{max}=386.6 \text{[A]}, 11 \text{ pulses}\)
- \(I_{max}=386.6 \text{[A]}, 13 \text{ pulses}\)
- \(I_{max}=386.6 \text{[A]}, 13 \text{ pulses}\)

- Laser: rms size
  - \(\alpha_x=0.37200\), \(\alpha_y=0.37200\) [mm]

- Electron beam:
  - Momentum gun:
    - \(\beta_x=6.46500\) [MeV/c]
    - \(\beta_y=14.76500\) [MeV/c]

- Monochromator:
  - \(\theta=0.75229\) [deg]

- Divergence:
  - \(\theta=0.93449\) [mm]
  - \(\text{covariance}=0.02447\) [mm mrad]
  - \(\text{sheared div}=0.03686\) [mm mrad]

- 2D:
  - \(\text{scaled}=0.991\) [mm mrad]
  - \(\text{unscaled}=0.997\) [mm mrad]
  - \(\text{2D}=1.060\) [mm mrad]
LOWEST EMITTANCE MEASURED

beam @ EMSY1

X-X’ phase space

Y-Y’ phase space

\[ \varepsilon_x = \left( 0.721 \pm 0.013 \right) \text{ mm mrad} \]

\[ \varepsilon_y = \left( 1.089 \pm 0.020 \right) \text{ mm mrad} \]

\[ \varepsilon_{xy} = \left( 0.886 \pm 0.011 \right) \text{ mm mrad} \]

(100% RMS emittance)

*Q=1nC*
*Imain=387A*
*Gun: +6deg off-crest*
*Booster: on-crest*
*Laser temp.: 2.1/23.1/2.4 ps*
*Laser BSA=1.5mm*

But! It was not possible to reproduce it in next shifts!
LONG TERM STATISTICS

Beam size and emittance at EMSY1 for BSA 1.5 mm
Charge of 1 nC, gun phase = -6 degree off-crest
laser 20 ps FWHM, 2 ps r/ft, Imain 384A

Short term (~3hours): ~4.7% (stdev)

Long term (~4days): ~6.8.5% (stdev)
~16.21% (peak-to-peak)*

\[ \varepsilon_x = 1.046 \pm 0.075 \text{ mm mrad} \]
\[ \varepsilon_y = 1.330 \pm 0.058 \text{ mm mrad} \]
\[ \varepsilon_{xy} = 1.179 \pm 0.052 \text{ mm mrad} \]
EMITTANCE VS CHARGE

<table>
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<tr>
<th>Laser rms spot size, mm</th>
<th>1 nC</th>
<th>0.5 nC</th>
<th>0.25 nC</th>
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<tr>
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<td>1.3</td>
<td>0.55</td>
<td>0.33</td>
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</tr>
</tbody>
</table>

Study of emittance vs. laser spot size and charge gun phase -6deg, booster on-crest

(100% RMS emittance data !)
Emittance measurement procedure has been accelerated (one continuous slit scan takes now ~20sec)

Low emittance for the nominal 1nC has been demonstrated. Several consequent measurements (22.08.2009M) delivered

$$\varepsilon_{xy}(100\%) = 0.886 \pm 0.011 \text{ mm mrad}$$

$$\varepsilon_{xy}(90\%) = 0.681 \pm 0.010 \text{ mm mrad}$$

but it was not possible to reproduce these measurements even in next shifts – the reason is phase instability e.g. average of 10 measurements on 13.09.2009:

$$\varepsilon_{xy}(100\%) = 1.178 \pm 0.052 \text{ mm mrad}$$

$$\varepsilon_{xy}(90\%) = 0.878 \pm 0.040 \text{ mm mrad}$$

Emittance has been measured for various bunch charges, low values have been demonstrated

$$\varepsilon_x(Q=0.25\text{nC, 100\%}) = 0.47 \text{ mm mrad}$$

$$\varepsilon_x(Q=0.25\text{nC, 90\%}) = 0.37 \text{ mm mrad}$$

$$\varepsilon_x(Q=0.1\text{nC, 100\%}) = 0.33 \text{ mm mrad}$$

$$\varepsilon_x(Q=0.1\text{nC, 90\%}) = 0.25 \text{ mm mrad}$$
LONG TRAIN OPERATION

700 pulses x 1 nC with 7 MW in the gun (23.01.2009A)

Laser scope

Bunch charge: LOW.ICT1

Beam position: LOW.BPM1

Long pulse operation (aver. current 7 μA) has been demonstrated, BUT laser pulse train envelope still to be improved
Colleagues actively participating in measurements & new design:

- **DESY, Zeuthen site:**

- **DESY, Hamburg site:**
  A. Brinkmann, K. Flöttmann, S. Lederer, D. Reschke, S. Schreiber

- **BESSION Berlin:**
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- **CCLRC Daresbury:**
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- **INRNE Sofia:**
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- **INR Troitsk:**
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- **LAL, Orsay:**
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- **LASA Milano:**
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- **LNF Frascati:**
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- **MBI Berlin:**
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- **TU Darmstadt:**
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- **Uni Hamburg:**
  J. Rönsch

- **YERPHI Yerevan:**
  L. Hakobyan

* on leave from BINP, Novosibirsk, Russia
** on leave from INR, Dubna, Russia
*** on leave from UCLA, USA
**** on leave from MEPHI, Moscow, Russia


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The end